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Impacts of and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh: A preliminary investigation

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A B S T R A C T

In the context of the exhaustion of marine fisheries, aquaculture increasingly plays a mounting role in the world economy and food security. However, it is confronted with and deeply affected by various threats and disruptions caused by global climate change. Bangladesh, a key site for global aquaculture production, contributes very little to global green-house gas emissions; however, it is one of the worst victims of climatic turmoil. While Bangladesh earns a large amount of foreign currency from the commercial shrimp providing livelihoods for millions, its goal of a sustainable aquaculture is recently hindered by its exposure to climate change vulnerability and extremes. Coastal Bangladesh, where shrimp is cultured, is frequently affected by extreme climatic disruptions like cyclones and storm surges that severely damage the entire coastal aquaculture. Drawing on primary and secondary data from Bangladesh shrimp industry, and using conceptual threads of climate vulnerability and resilience, this paper critically examines how and to what extent shrimp aquaculture in Bangladesh—located at the bottom of a buyer-driven commodity chain— becomes vulnerable and builds resilience to global climate change.

Statement of relevance:

- Aquaculture in the coastal Bangladesh is one of the worst victims of global climate change.
- Shrimp aquaculture is frequently affected by cyclones and storm surges.
- Worst victims are the small scale farmers and fry collectors located at the bottom of a buyer-driven commodity chain.
- Most small *bagda* farming households in Bangladesh do not seem to be resilient in any meaningful sense.

1. Introduction

Climate change is real and human beings are responsible for a substantial part of it (Ciplet et al., 2015; Islam, 2013). With growing human contribution to global warming, it is now apprehended that the current trajectories of climatic anomalies will exacerbate existing vulnerabilities and may have striking repercussions for natural and social systems around the globe. Through its intense and unsettling consequences in different regions and sectors, climate change impacts human communities in many ways – the majority of which are compound, indirect, and ambiguous (Pelling, 2011). Global aquaculture, a fastest growing food system of the world (Bush et al., 2013), is affected by social and environmental perturbations; and as a climate-sensitive social-ecological system, it is profoundly impacted by climatic variations and extremes as well. In the changing conditions and growing vulnerabilities, aquaculture communities throughout the world espouse their own coping strategies.

Commercial shrimping in Bangladesh[1] entails the characteristics of a complex sea-food supply chain (Gammage et al., 2006). Although wild shrimp *capture* is a century-old phenomenon in the coastal zones of Bangladesh, shrimp *culture* started in the late 1960s when several fish-freezing plants were established in Chittagong and Khulna (Islam,

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[1] Coastal aquaculture in Bangladesh consists mainly of two shrimp species: (a) brackish-water marine shrimp, *Penaeus monodon* (tiger shrimp, locally called *Bagda Chingri*) and (b) fresh-water giant prawn, *Macrobrachium rosenbergii* (locally called *Golda Chingri*). There are about 16,237 marine shrimp farms covering 148,093 ha and 36,109 fresh water prawn farms covering 17,638 ha of coastal area in Bangladesh (Azad et al., 2009:800). In popular usages, especially in government statistics and scholarly writings in Bangladesh, both species are frequently referred to as 'shrimp'. The FAO convention is to call the marine and brackish-water species 'shrimp' and freshwater species 'prawn' (FAO, 2008). Since the empirical part of this study was conducted in brackish-water area, 'shrimp' is generally used to mean *Penaeus mondon* throughout the report; but, to make it comprehensive, this term includes *Macrobrachium rosenbergii* and other penaeid species when referring to previous studies and statistics on shrimp.

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2008b). Rising demands on natural marine shrimp stocks and maximum harvesting in available areas enhanced the commencement of extensive shrimp cultivation in the coastal areas (Azad et al., 2009). Fresh-water prawn farming took off around 1978 when a small number of wealthy farmers in Bagerhat district in the southwest Bangladesh began to experiment with stocking prawn in carp ponds (Rutherford, 1994; Ahmed et al., 2008; Ahmed et al., 2010). Later, with the immersion of the government and international donor agencies, the export-oriented shrimp industry in Bangladesh started in the early1980s, when shrimp farming in higher-income East-Asian countries confronted with ecological, environmental and social damage and the industry expanded to less developed countries of South Asia (Ito, 2002; Islam, 2014). Based on both wild and hatched post-larvae (PL),[2] the shrimp industry in Bangladesh – accounting for about 5% of total export income – has become the country's second largest export item after ready-made garments since the 1990s (Ahmed, 2013; Islam, 2008a, 2008c). Bangladesh earned USD 454.93 million in the year 2012–13 by exporting shrimp mainly to the EU countries, the United States, and Japan (BFFEA, 2014: 95). Bangladesh exported 54,891 tons of prawn and shrimp in 2010–11, of which 30% was contributed by prawn and the remainder (70%) by shrimp (Ahmed, 2013: 38).

The expansion of shrimp industry in developing countries like Bangladesh is hailed by many as 'blue revolution' (Islam, 2014) or 'pink revolution' (Delap and Lugg, 1999) because of its enormous potentiality to earn desperately needed foreign currency for the producing countries. However, shrimp farming system in Bangladesh significantly differs from that in other Asian countries especially in terms of method of cultivation and production output. While aquaculture firms in Taiwan, Australia and Thailand adopt intensive method, Bangladeshi farmers largely depend on traditional, extensive and improved extensive methods of cultivation. In Bangladesh, though horizontal expansion of shrimp cultivation and total amount of production has increased over the years, shrimp yield per unit of land has shown very little or no improvement. Table 1 demonstrates that comparing with other countries in the region, per unit shrimp production in Bangladesh is very low.

The productivity level could be increased through improved technologies, better scientific management, and more investments. The productivity and sustainability of this vital coastal livelihood depend on technological and physical-environmental inputs and conditions as well as on the social organizations surrounding it. Although commercial shrimping in Bangladesh provides a wide range of economic benefits, its location at the critical juncture of human and nature makes it vulnerable. The nature of the livelihood vulnerability in the coastal shrimp regime lies at the critical intersections between the physical arrangements of the *gher* (farm) structure, the biology of shrimp genesis, the prevailing agrarian social structure, and the community level endeavors. Shrimp aquaculture in Bangladesh, situated at the bottom of a primarily buyer-driven commodity chain, bears the brunt of climate change repercussions. Although Bangladesh contributes negligibly to global greenhouse gas emissions,[3] it is ironically one of the worst victims of climate turmoil.[4] Similarly, the shrimp industry in Bangladesh, as a part of global industrial aquaculture, is deeply affected by climate change. In this article, we examine the specific impacts of, and the extent of resilience to, climate change in the shrimp aquaculture in Bangladesh.

Table 1
Shrimp production comparison among selected countries.
Source: Adapted from Aftabuzzaman (2010) and Rönnbäck (2001).

Country (1999)	Shrimp yield (kg/ha/year)
Taiwan	4000
Australia	4000
Thailand	2500
Malaysia	1500
Bangladesh (2009)	633

This study is framed by two conceptual threads: climate change vulnerability and resilience (Section 2 below). In the Section 3, we have explained the methods of data collection for this study. Section 4 provides a detailed examination of climate change vulnerabilities in the wake of global climate change focusing on, for example, cyclone and storm surges, increase in atmospheric and water temperature, draught, heavy rainfall, intrusion of salinity, sea level rise, and erosions of riverbanks. Adaptation and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh have been adumbrated in Sections 5 and 6. The paper in Section 6 concludes by summarizing our findings and signaling the future adaptive mechanisms at the bottom of the Bangladesh shrimp commodity chain.

2. Conceptual framework

2.1. Climate change vulnerability

Over the last decades climate change has become perhaps the most prominent global environmental issue for academia, policy makers, media, and people (Islam, 2013; Ciplet et al., 2015). The current phase of global warming since the Industrial Revolution is unique on two grounds – "it is *man-made* and it is happening more *speedily* than any time in the last fifty million years" (McKinnon, 2012:1, emphasis in original text). Modern capitalistic treadmill of production is responsible for exacerbating greenhouse gas (GHG) emissions in atmosphere in countless ways by producing and consuming energy in agricultural, industrial, commercial, transportation and other uses. Global fossil fuel burning is rising every year; and if the trajectory continues, human society and natural ecosystems will be affected drastically. The repercussions of global warming will be felt most in geographically and socially vulnerable as well as climate-sensitive regions, communities, and sectors (Baer, 2012; Kais, 2017).

As a climate-sensitive sector, industrial aquaculture in the tropical regions will be affected by the majority of projected changes in global climate. The intersections between climate change impact, adaptation, and aquaculture has drawn considerable scholarly interest in recent years.[5] Climate change related threats to aquaculture arise from (*i*) stress due to increased temperature and oxygen demand and decreased pH, (*ii*) uncertain future water supply, (*iii*) extreme weather events, (*iv*) increased frequency of diseases and toxic events, (*v*) sea level rise and conflict of interest with coastal defenses, and (*vi*) an uncertain future supply of fishmeal and oils from capture fisheries (Brander, 2007). Predicted climate changes such as rise in water temperature, precipitation, sea level rise, extreme events like cyclones and tidal surges, soil erosion, climate variability and ocean currents will cause physiological (growth, reproduction, disease etc.), ecological (organic and inorganic cycles, predation, ecosystem services etc.) and operational (species and site selection etc.) changes (Handisyde et al., 2006). All these changes will have direct impact on aquaculture production and aquaculture

[2] Although wild shrimp fry catch from open water is prohibited in Bangladesh and Bangladesh produces shrimp fry more than its demand producing over 10,350 million of shrimp hatchlings in 2013 by 61 *bagda* and 70 *golda* hatcheries (BFFEA, 2014), shrimp farmers still yearn to use wild fry in their *ghers* because of their better survival rate.

[3] Bangladesh has almost zero contribution to the global warming with a per capita GHG emission of 0.37 metric tonnes (mt)/year (ranking 174 out of 214 countries), comparing to that of USA 17.5 mt/person/year and 26–53 mt/person/year in oil-rich Middle East countries (Rashid and Paul, 2014:7). In 2008, for instance, Bangladesh contributed only 0.14% of global CO_2 emission (Ahsan et al., 2011:122; Rashid and Paul, 2014:7).

[4] Bangladesh was afflicted by at least 174 natural disasters between 1974 and 2003 (Reid, 2014:126).

[5] E.g. De Silva and Soto, 2009; Brander, 2007; Handisyde et al., 2006; Chand et al., 2012; Williams and Rota, 2013; FAO, 2009, 2011; Brugère, 2015; Mills et al., 2011; Khan et al., 2012; Frost et al., 2012; Young et al., 2012; Shelton, 2014; Edwards, 2015; Kam et al., 2012; Nagothu et al., 2012.

dependent livelihoods and indirect influences on aquaculture through fishmeal and fish oil availability (Handisyde et al., 2006; De Silva and Soto, 2009; FAO, 2011; Chand et al., 2012). Only after a thorough analysis of contextual factors affecting exposure, sensitivity, and adaptive capacity of aquaculture communities and stakeholders, realistic adaptation and resilience plans and actions can be devised for specific groups and communities. In addition to aquaculture species' biophysical and environmental influences, several socio-economic, networking and governance factors act as determinants of resilience for human communities dependent on aquaculture.

2.2. Resilience

Resilience of a system (or community) incorporates both static and dynamic properties (Kais and Islam, 2016; Kais, 2017). On the one hand, resilience is conceptualized as an inherent or antecedent condition or state or 'outcome' (Cutter et al., 2008; Reid and Botterill, 2013; Rose, 2004, 2007). In other words, a community's inherent resilience denotes its ability to function well under normal circumstances in non-crisis periods and its ability to reinstate the pre-crisis stability after a shock. On the other hand, a system's resilience is also its adaptive quality during and after a crisis – it is a 'process'. In this view, resilience is not a fixed property of the system; rather, it incorporates the idea that a resilient system has flexibility in responding to hazards in that the system's initial structure or function might undergo some necessary changes. Here we can discern at least two types of resilience: outcome-oriented and process-oriented. While outcome-oriented resilience schemes tend to espouse 'command and control styles' which aim to retain the social status quo, process-oriented disaster resilience schemes focus on series of actions that enhances a community's coping capacity over time (Kais and Islam, 2016; Kais, 2017).

In the context of shrimp-farming communities in Bangladesh, 'resilience strategy' means any action taken by the farmers (or, other stakeholders) that help them survive and sustain in facing adverse climate impacts on their farms. In this study, we examined both outcome-oriented and process-oriented resilience schemes adopted by the shrimp-farming communities in Bangladesh. Outcome-oriented measures at the farm level include putting net around the farms to prevent shrimp escape (during floods and heavy rainfall), increasing the height of dikes (responding to storm surges), and increasing the depth of farms (in addressing the excessive heat conditions). The process-oriented measures at the household level include diversification of livelihoods in responding to overall loss in shrimp production due to climate disasters. The specific resilience strategies are discussed in detail in Section 5.

3. Materials and methods

In order to examine the intersections between global climate change and resilience in the shrimp farming communities in Bangladesh, a field-level investigation in Bangladesh was conducted from March 2014 to July 2014. A triangulation of methods – incorporating content analysis of secondary sources, ethnography and qualitative interview – was adopted in collecting data. The whole subject of climate change vulnerabilities and resilience mechanisms in Bangladesh context is so complex and diverse that we had to apply multiple methods in order to acquire a comprehensive insight into the sector. In order to get a full picture of the historical as well as current scenario of the climate change and resilience in Bangladesh, at first an 'unobtrusive' or 'nonreactive' (Babbie, 2013) research based on content analysis of existing secondary documents in Bangladesh was conducted. In the next phase of data collection, we conducted an ethnographic study in the shrimp farming areas in the south-western region of Bangladesh. In order to fully grasp the local dynamics of shrimp cultivation, climatic issues, and resilience mechanisms, the authors conducted three ethnographic visits in Bagerhat, Khulna and Satkhira districts in south-western coasts of Bangladesh, staying for two weeks in each of the sites. These districts were selected purposively because of some compelling reasons. First, these three districts comprise about 80% of total shrimp farms in Bangladesh (Pokrant and Reeves, 2003; Islam, 2008a). Second, these areas are most vulnerable to climate change events like tropical cyclones, sea-level rise, salinity intrusion, and storm surges (Ali, 1996, 1999; Ahmed et al., 2013; Ahmed, 2013; MoEF, 2008). Finally, adaptation initiatives by Bangladesh government and NGOs are being taken in these areas in order to face climate change vulnerabilities (MoEF, 2008). At the final stage, after having a clear understanding of the local dynamics, a section of informed group – comprised of shrimp farmers, fry collectors and shrimp and fry traders – was interviewed in order to complement the ethnographic data. In this study, we viewed the stakeholders who are directly engaged in farm-level shrimp production as the 'bottom' of the shrimp commodity chain. Thus, our focus was on the exact dynamics in the farming villages, not in the shrimp processing factories or plants. For close observation of the climate change impacts and adaptive strategies, three shrimp-farming villages – namely Haldibunia of Mogla Upazila in Bagerhat, Gazi Para of Koyra Upazila in Khulna and Ghar Kumarpur of Shyamnagar in Satkhira – were randomly selected.

4. Climate change vulnerability in Bangladesh shrimp aquaculture

Climate change vulnerability is analyzed in the literature by means of three sequential and essential conditions. First, people of a community may be more or less exposed to climate hazards in the sense that they do or do not experience such hazards or changing climate conditions more generally. Second, climate extremes and changes may affect the income sources, livelihood, and assets of households more or less. Finally, households may show more or less resilience to weather shocks and changes when their income sources, livelihood, assets and food security are affected (Schroter et al., 2005; Wodon, 2015). Since climate change is an emerging global issue, researchers tend to deal with broad aggregates, concentrating on global, regional, and national level impacts and vulnerabilities. Discerning impacts of climate change, especially slow onset changes, on small village communities is a fairly recent trend.

The vulnerability context of Bangladesh and its people emanates from multiple components including exposure, sensitivity, biophysical, and socio-economic factors. Because of the country's unique geographic location and hydro-geological characteristics, the future of Bangladesh is now unfortunately "trapped between the melting Himalayas in the north and the encroaching Bay of Bengal to the south" (Rahman et al., 2009:13). Bangladesh is surrounded by mountains and hills on three sides – Rajmahal hills in the west, the Himalayas and the Meghalaya Plateau in the north and Tripura-Chittagong hills in the east – a fact that makes the country a discharging route for the huge amount of rainfall-runoff and snowmelt water from the Himalayas (Rahman and Salehin, 2013). Bangladesh lies in the lower part of the GBM (Ganges-Brahmaputra-Meghna) basin. The total drainage area of the GBM basin is about 1.55 million km^2, only 9% of which is within Bangladesh (Rashid and Paul, 2014:13). Riverine floods in Bangladesh are primarily caused by excessive rainfall in the upper catchment areas of the GBM basin in India, Nepal, Bhutan and the Tibetan region of China. The GBM rivers have a combined peak discharge of 180,000 m^3/s during the flood season, second in the world after the Amazon (Rawlani and Sovacool, 2011:848). About 91% of the total annual water flow of Bangladesh enters from upper riparian countries through 57 international rivers. The above factors make the country susceptible to annual flooding on a regular basis. The topography of the country is low and flat with 80% of its landmass covered by floodplains (Rahman and Salehin, 2013:69). About 10% of the country is within a 1-metre-height range from mean sea level (MSL), one-third is under tidal excursions, and two-thirds of its critical infrastructure is < 5 m above MSL (Rawlani and Sovacool,

2011), making the country vulnerable to inundation by riverine floods, storm surges, and sea-level rise (SLR). The country faces two major hydrological hazards, floods in the wet season and droughts in the dry season, because of highly skewed temporal variation of precipitation. About 80% of the annual rainfall occurs during the monsoon season, while in the winter, the country becomes rainless for months. Moreover, the coastal make-up of Bangladesh, with an inverted-funnel shaped GBM estuary, amplifies cyclone storm surges when they approach the coast (Rashid and Paul, 2014).

In addition to above geo-morphological and physical features, the climate sensitivity of Bangladesh is also determined by a number of socio-economic factors that affect resilience of the people of Bangladesh to climate hazards. Bangladesh is a highly populated country with a total population of over 168 million (July 2015 estimate) – ranking 9th in the world and with a density of 1132 people/km^2 (CIA, 2015). Bangladesh is also a poor country with a significant portion of its population living under poverty line. Many of the extremely poor have no employment or income and suffer from continuous food insecurity, malnutrition and social vulnerability, being deprived from access to civic amenities like health and sanitation services, safe drinking water and education for their children. With a per capita income of only USD 1314 (bdnews24.com, 2015) and with 49.4% of the total population in multidimensional poverty[6] (UNDP, 2015:61), a substantial section of people, especially among the coastal and slum-dwellers, are forced to live in fragile ecosystems in hazard-prone areas, which makes them even more vulnerable and less resilient to climate change and other disasters. At community level, social vulnerability depends on several factors including location and pattern of settlement, land management systems, means of livelihood (e.g. dependence on weather-sensitive sectors like agriculture and fisheries), and pattern and sufficiency of infrastructure, among others. Low economic strength, insufficient infrastructure, low level of social development, lack of institutional capability, and higher dependency on the natural resources make the people of Bangladesh increasingly vulnerable to geo-hazards, particular forms of human-nature interaction leading to mankind's settlement in endangered regions despite potential threat (Islam et al., 2013; Neverla et al., 2012).

Climate change variability and extremes that affect shrimp farming in the coastal Bangladesh include atmospheric and water temperature increase, coastal tidal surges and flood, cyclone, saline water ingression, sea-level rise etc. The overall impacts incorporate individual as well as combined negative consequences of climatic phenomena on physiology (reproduction, metabolic activities etc.) and growth of shrimp, which lead to reduction in net shrimp production, which in turn leads to low economic output from the sector adversely affecting the farmers' livelihood and food security, and the country's export earnings and GDP. Increasing intensity and frequency of climatic extremes may also damage shrimp-farming infrastructures. In the course of the field research for this project in south-western regions of Bangladesh where shrimp is cultivated, the following negative effects of climatic disasters and disruptions were found.

4.1. Cyclones and storm surges

Cyclones and storm surges have devastating effects on the physiology of shrimps, *gher* [pond] structures, shrimp ecosystems, and surrounding infrastructures. After the cyclones *Sidr* and *Aila,* which hit coastal Bangladesh in 2007 and 2009 respectively, most of the shrimp farms in south-western regions of Bangladesh were washed away. Cyclone *Sidr*, with a sustained wind speed up to 250 km/h and storm surges up to 9.1 m, affected 8.7 million people in 30 districts of the country, leading to 3400 deaths and over 55,000 people injured. One million households lost their dwellings (Siddiqui and Billah, 2014). A total of 567,000 people lost their main source of livelihood either permanently or temporarily (ILO, 2008). Making landfall during high tide in late May in 2009, cyclone *Aila* was associated with tidal surges of up to 6.5 m, affecting a total of 3.9 million people in 11coastal districts (UN, 2010; Siddiqui and Billah, 2014). This surge of water damaged partially or fully over 1742 km of embankments, removing the only safeguard available to many households in the coastal areas. The instant impact of Cyclone *Aila* resulted in 399 deaths and approximately 7100 injuries. About 100,000 livestock were killed, and almost 350,000 acres of crop land were damaged. *Aila* destroyed partially or fully about 5000 institutions of various categories, and 157 bridges and culverts (UN, 2010). In addition to these two, cyclones strike the south-western coast of Bangladesh more or less frequently and cause huge damages.

Sidr destroyed 54,000 shrimp *ghers* (Siddiqui and Billah, 2014), causing Bangladesh to incur a loss of US$ 36 million (Ahmed and Diana, 2015a). According to key informants of this research, about 90% of shrimp *ghers* in Shyamnagar and Koyra and about 80% in Mongla were damaged by *Aila*. According to the farmers, storm surges inundate shrimp *ghers* which causes shrimps to escape out from the ponds resulting in economic loss to the farmer. An assessment by the Department of Fisheries and FAO indicates that production of shrimp in *Aila* affected areas was reduced by 80% from a normal year's production (UN, 2010). Since the embankments along the rivers were destroyed by *Aila*, shrimp farmers could not cultivate shrimp for one or two seasons, based on the location of *ghers*, because the whole farming areas were under water. Farmers also reported that lot of predators (shrimp-eating fish and aquatic animal species) entered shrimp *ghers* at the time of *Aila*, causing a reduction of shrimp production.

Moreover, cyclones in the coastal areas cause contamination of pond water through debris and wastage intrusion which deteriorates the parameters of *gher* water that in turn causes disease and death outbreak or under-growth of cultured shrimp. If turbidity of water increases due to contamination, the gill of shrimp may choke because of accumulation of foreign substances dissolved in turbid water. The production of natural food for fish, i.e. phytoplankton, drops in turbid water (Roy et al., 2011). Consequently, the shrimp encounters food shortage and difficulty in breathing, and loses appetite; and in extreme condition it may die. Decomposition of organisms in *ghers* due to storm surge inundation causes a sharp decline in dissolved oxygen (DO) in water (Ahmed and Diana, 2015b). The ideal level of DO content in *gher* water is 5.0–8.0 mg/l for optimum growth of shrimp. Shrimp cannot continue its normal physiological activities if DO content level in water goes below 2.0 mg/l (Roy et al., 2011). Thus, through increasing turbidity and decreasing DO level in *gher* water, cyclones and storm surges pose existential threat to cultured shrimp. Moreover, flooded storm surge water frequently contributes to changes in the salinity of pond water which affects shrimp growth.

Cyclonic storms also destroy shrimp farming equipment. Farmers reported that they lost *patas*[7]*, bajras*[8]*, khachis*[9] and *charus* or *atols*[10] during severe storm surges of the *Aila*. Cyclones also damage shrimp farmers' houses, leaving them in distressed condition. After cyclone *Aila*, 5009 families in Koyra and Shyamnagar were forced to live in cyclone shelters or on embankments and roads for months (UN, 2010). During that precarious time, they were stuck with their own existence and could not concentrate on taking care of their farms which in turn

[6] *Multidimensional poverty* is a broader concept of poverty, comparing to the classical concept of poverty line. It is calculated as a weighted average of 10 socio-economic indicators. A person is considered to be in multidimensional poverty if she or he is deprived in at least a third of these indicators, with each indicator having a defined deprivation level (UNDP, 2015).

[7] *Pata* is a kind of protector made of bamboo sticks, used on the path of water passage during exchanging *gher* water so that shrimp or other fish does not go out of the *gher*.

[8] *Bajra* is a basket made of bamboo sticks, used for collecting harvested shrimp.

[9] *Khachi* is a type of net used for collecting harvested shrimp.

[10] *Charu* or *Atol* is a piece of equipment (trap) made of bamboo sticks and used to catch shrimp from *gher* on regular basis, especially during springtides.

caused production losses. Severe cyclonic storms cause damages to roads and communication infrastructure in the shrimp farming areas which hamper the transportation and marketing of harvested shrimp. *Aila*, for instance, destroyed partially or fully about 9000 km of road in the affected areas. Most of the roads damaged by *Aila* were in Koyra, Mongla and Shyamnagar. Instead of road transports, people had to use water vessel in order to move. Sometimes *katas*[11] went under water during high tide in the rivers. Thus, business of shrimp commission agents and shrimp traders was also hampered severely. During the exact time when *Aila* crossed the research areas (11 AM–4 PM, May 25, 2009), a number of shrimp carrying vans were in operation on the road. Almost all of those vans were washed away by the cyclone causing significant loss to the traders. According to shrimp traders of Bongshipur in Shyamnagar, some of their fellow traders were forced to withdraw from business for few months because of *Aila*. Moreover, due to sharp decrease in shrimp production in the locality, shrimp business was dull up to 2 years after *Aila*.

4.2. Increase in atmospheric and water temperature

With rising air temperature, water temperature in shrimp *ghers* increases (Piccolroaz et al., 2013; McCombie, 1959), resulting in adverse impacts on ecosystems functioning in *ghers* and in turn causing lower productivity. Farmers reported that water becomes extremely hot during summer days. Two main causes were found: first, increased atmospheric temperature; and second, shallowness of the *ghers*. The ideal temperature range for the growth of shrimp is 28–32 °C. At a temperature lower than 25 °C, shrimps may become disease infected because of stress; while with > 35 °C shrimps become weaker and ultimately die (Roy et al., 2011). In south-western coast of Bangladesh, water temperature in shallow *ghers* sometimes goes over the tolerable limit for shrimp PL as well as for matured shrimps. Also, the availability of wild fry in rivers declines due to the rise of water temperature.

Increase in air and water temperature during summer months causes pond water extremely hot in which metabolic activities of shrimp are severely influenced. Increased temperature in the *gher* environment (i.e. soil and water parameters) increases the physiological activities of shrimp (Weiss, 1970), requiring additional dissolved oxygen (DO) in pond water. But the level of DO is inversely related to temperature and salinity, i.e., if temperature and salinity of water increase, the DO level decreases (Farzana and Hossain, 2015). This situation hampers growth and reproduction success of shrimp. Furthermore, increase in water temperature frequently causes stratification and less nutrient enrichment to surface waters, which in turn leads to reduced growth in shrimp (Harley et al., 2006; Ahmed and Diana, 2015b). Moreover, water depth of shrimp ponds decreases with the increase in atmospheric and water temperature because of evapotranspiration which reduces the total volume of water in the *ghers*. Generally, DO concentration in *gher* water comes to its lowest level after midnight when all aquatic organisms respire and, as a result, shrimps face hypoxic condition (Farzana and Hossain, 2015). Thus, the amount of O_2 in water falls below the essential level for the physiological activities of shrimp; and accordingly, shrimps growth rate and reproductive output reduce and sometimes they die en masse. Shrimps also lose appetite in extreme hot water, which reduces their food intake and growth.

According to the shrimp farmers, brackish water heats up quickly compared to freshwater. Shrimps are more affected by bacterial diseases when water becomes too hot. According to them, bacteria become active in increased temperature, leading to contamination of the entire *gher* environment. Farmers from Mongla area classify their *ghers* into two types: *boddho gher* (closed farms, which are enclosed by dykes on four sides without any provision of regular flushing of tidal surge) and *shorboraho gher* (supply farms, which are attached to Pasur River and connecting canals and have provision of regular water exchange throughout shrimp cultivation season). Water becomes hot quickly in those *ghers* which are not deep enough. If water temperature crosses the threshold level, shrimps have to suffer bad consequences. For this reason, shrimps die in very hot temperature, especially in the shallow *ghers*. Since there is no embankment of the Bangladesh Water Development Board (BWDB) in Mongla Upazila, water level in the *shorboraho ghers* are directly related to water availability in the Pasur River. During neap tide, water depth decreases and if the temperature is increased severely at that time, shrimps cannot survive in those *ghers*.

Shrimp fry are transported from Cox's Bazar to Khulna region: from Cox's Bazar to Jessore by air and from Jessore to shrimp farming areas on road. Shrimp PL is carried in cock-sheet boxes in which ice is put in order to keep water temperature at optimum level. But in hot weather, cock-sheets also become hot; sometimes leading to the death of a portion of PL. Moreover, the PL cannot be stocked in the *ghers* quickly because of excessive temperature in *gher* water.

Since total volume of water decreases due to increased temperature, the density of shrimp population increases in the *ghers*. As a result, they have to struggle to get sufficient O_2 from water. However, the volume of water decreases in hot climate but the total volume of salt in water remains same; the salinity level in water increases. Although *bagda* is a saline-tolerant species, it also requires an optimum level of water salinity, a deviation of which affects their growth.

Shrimp traders reported that ice melts quickly in hot weather. If ice melts out quickly from shrimp carrying vans, quality of the shrimps deteriorates. So, in order to retain the optimum physical quality of shrimp, including color and temper, in hot weather, traders have to apply larger amount of ice for preserving, processing, and transporting shrimps. As a result, their icing costs rise in increased air temperature.

4.3. Drought

In addition to increased temperature in air and water, prolonged rainless time occurs in some years leading to drought condition in the areas. Impact of drought on shrimp cultivation depends on the availability of required amount of water. Although drought is not a very common problem for shrimp farming in the research areas because most of the *ghers* use river water for cultivation, prolonged droughts sometimes result in short culture periods for shrimp, especially in the highland and in the areas far from rivers. Seasonal pre-monsoon drought increases water temperature and salinity that have an adverse effect on shrimp production. Aquaculture farmers in Koyra, Shyamnagar and Mongla experienced few droughts. During droughts, water levels in *ghers* drops sharply. The farmers who can exchange water from river do not face this problem; however, if their *ghers* are further inland, they cannot take effective measures. One such farmer grieved, "Our *gher* water is becoming poisonous, ppt (i.e. salinity) is rising, shrimp production is decreasing, and virus is coming." According to a news report, shrimp farmers in southwest Bangladesh struggled with a drought situation in April 2014 that caused a loss of US$ 225 million worth of shrimp and fish fry (Financial Express, 2014). Droughts also have chain effects on the shrimp farmers' food security and food consumption.

4.4. Heavy rainfall

Increased rainfall also hampers shrimp ecosystems. Excessive amount of rainfall causes turbidity in water. Water transparency level of 25 cm in *ghers* indicates sufficient amount of natural food in the water (Roy et al., 2011). If this level falls due to intrusion of debris and organisms in water, sufficient sunlight penetration is hampered and the production of phytoplankton is seriously affected at the deeper level by

[11] *Kata* is the market place where shrimp farmers and *farias* sell their shrimp to shrimp traders through shrimp commission agents.

reduced photosynthesis; phytoplankton is then produced only at the upper layer of the *gher* water. As a result, shrimps suffer from food shortage which in turn retards their growth. Moreover, turbid water causes breathing difficulties and loss of appetite in shrimps which also result into lower growth rate. Torrential rainfall also reduces the pH level in *gher* water. For shrimp culture, the optimum pH range in water is 7.5–8.5. If pH reaches to below 4 or above 11, shrimp may not survive (Roy et al., 2011). Furthermore, extreme rainfall causes the DO level in *gher* water to fall (Farzana and Hossain, 2015). Appetite of shrimps increases when DO level increases; and appetite drops with a decrease in DO level in water. Through all of these mechanisms, heavy rainfall challenges shrimp physiology and ecosystems.

Farmers from the fields reported that *gher* dykes submerge if excessive rainfall occurs for a long period (few hours). As a result, shrimps escape from the *ghers* and farmers incur loss. Also, shrimps frequently die in heavy rains, especially if it occurs at the start of the monsoon. Three things are worth mentioning here. First, the first rain of the monsoon, with thundershowers, is acidic with low pH (pH < 7). Rainwater during this time is associated with various elements from atmosphere including few gaseous components, dust and debris. But after few days, from the middle of the monsoon, rainwater becomes neutral. So, when acidic rainwater mixes with the *gher* water, the *gher* environment becomes upset, changing in existing water and soil parameters. Second, at the start of monsoon, *gher* water remains hot because of excessive water temperature; however, rainwater is comparatively cold. Mixing of hot and cold water upsets the water parameter in *ghers*. Finally, *gher* water is brackish, while rainwater is fresh. Therefore, mixing of saline and freshwaters create an ecological imbalance in the *gher* which leads to adjustment problem for the shrimps in *gher*. Existing literature indicates that low level of water salinity with water temperature fluctuations of 3–4 °C results in the outbreak of white spot syndrome virus (WSSV) in shrimp (Tendencia and Verreth, 2011).

Since few *gher* dykes submerge during exceptionally heavy rainfall, shrimps escape from *ghers* at that time. However, according to the aquaculture communities, shrimps from *ghers* try to go out during heavy rains even if the dykes are not submerged. They crawl over dykes; and the farmers try to prevent them. They also informed that marketing of shrimp and shrimp fry becomes problematic in intense rains because of poor roads and transports at least in some areas. This is particularly true for Mongla–Haldibunia, Shyamnagar–Nowabenki, and Koyra–Khulna roads. The conditions of these roads are severely bad with damages and deep patches on them. Shrimp communities also reported that they become more engaged in other works during rainy days including repairing their houses. Thus, working hours and days on *ghers* are reduced at that time. According to shrimp fry collectors, sometimes heavy rainfall causes a decrease in the availability of shrimp fry in the rivers since salinity of water becomes low at the upper level.

4.5. Salinity ingress

In general *bagda* is a brackish-water species that can survive in water with a salinity range of 5–40 ppt (Ahmed and Diana, 2015a); the optimum salinity range for this shrimp culture is 10–25 ppt (Roy et al., 2011). Salinity beyond this limit hampers the growth of shrimp. So, increased salinity itself may be problematic for shrimp metabolism. Salinity in coastal Bangladesh has been increasing in recent time. Farzana and Hossain (2015) found surface water salinity range of 7–46 ppt in shrimp *ghers* in Shyamnagar. If water salinity in the farm crosses the threshold limit, growth and survival rate of hatched PL also decreases. Increased water salinity can have a number of secondary impacts on shrimp physiology and ecosystems. Since there is an inverse correlation between salinity and DO level in water, if salinity level increases, the DO level decreases. The growth and existence of shrimp may be threatened in a lower DO regime, which we have already discussed in a previous section. Kautsky et al. (2000) concluded that fluctuations in water temperature and salinity are accompanied by occurrence of diseases in shrimp.

Aquaculture communities in southwest regions of Bangladesh recognize salinity intrusion as number one problem for the sustainability of the commercial shrimp. They opined that at the root of every environmental problem, shrimp or non-shrimp related, is ground and water salinity. Even the livelihood on bagda farming is threatened by saline water and soil. Shrimp PL, especially the hatchery ones, struggles for survival in the *gher* water. Farmers observed that nearly 80% of hatchery shrimp PL die after they are stocked in the farms. Overall production of shrimp is decreasing because of increasing salinity. With increased temperature, salinity level in water increases. Disease spreads in shrimp farms with an increase in water salinity. On an average, a farmer experience disease outbreak in his *gher* once in a year. But this saline disaster is not so much highlighted in the media. One shrimp farmer from Mongla commented, “The whole world knows about the disasters of *Aila* and *Sidr*; world people watched through satellite (i.e. TV); all came to support us. But no one knows about the ‘disaster under water’ (i.e. salinity); no satellites telecast this silent disaster.”

Aquaculture communities, especially shrimp farmers from Mongla area, pointed to climate change phenomena – such as cyclones, storm surges, temperature rise, SLR – as well as withdrawal of river water upstream as the causes of gradual increase in water salinity in the area. The Pasur River is a tributary of the Padma (Ganges). They opined that upward flow of saline water from the Bay of Bengal increases when India withdraws water from the Ganges at the Farakka Barage during dry season. In the monsoon, on the other hand, when more rainfall occurs in the area and India releases water of the Ganges, salinity level decreases. They also lamented that while two or three crops annually are cultivated in other regions of the country, even the cultivation of only one agricultural crop in the salinity zone is very hard.

4.6. Sea-level rise (SLR)

Several studies show that the western part of the coastline is highly vulnerable to sea-level rise (SLR) due to thermal expansion of ocean water and increased melting of glaciers and ice caps because of global warming (Sarwar and Mahbub, 2013; Rashid, 2014). Since the coastal area of Bangladesh is neither uniform nor static (Brammer, 2014a, 2014b) and since the net loss of land due to SLR in any area depends on many factors including accretion and erosion, different regions are vulnerable to SLR in different degrees. The western coast of Bangladesh is highly vulnerable, the central coastal regions are highly or moderately vulnerable and the east coast is the least vulnerable to SLR (Rashid, 2014). The IPCC projection of a one metre SLR by 2100 might submerge at least one-fifth of the country's total landmass (Rashid and Paul, 2014: 2); and a possible 45-cm SLR by 2050 could inundate 75% of the *Sundarbans*, the largest mangrove ecosystem in the world which cater to the shrimp cultivation in the south-western Bangladesh (Nishat and Mukherjee, 2013: 43).

While SLR affecting Bangladesh is obvious, it has yet to affect the shrimp *ghers* in the region in full scale. Although it does not reach at a level to inundate the shrimp farms, some indirect consequences are already felt by various stakeholders in the shrimp supply chain. If the sea-level rises sharply, the low-lying shrimp farms may be submerged causing production losses. This can happen especially in the areas outside BWDB embankments. In Mongla, for example, there is no embankment; thus owners of *ghers* close to the Pasur River remain worried about inundation any time especially during springtides when river water peaks. Also, in Shyamnagar and Koyra, people are always in tension about river bank erosion due to the rise of water level in the rivers. Changes in mangrove ecosystem in the Sundarbans due to SLR can alter breeding season and breeding success in shrimp (Ahmed and Diana, 2015a). Shrimp fry catchers who operate in the Sundarbans reported that their fry catch has dropped significantly comparing to that in ten years ago. Fry collectors reported that now their catch has

dropped also because they face problem in setting their nets in strong currents due to SLR.

4.7. Riverbank erosion

Riverbank erosion is a common natural hazard in the shrimp farming areas, especially in Koyra sub-district of Khulna. Coastal areas are cyclone-prone areas. Storms of low intensity hit this area almost every year. These storms act as threats to the embankments. Almost each year embankments breach at one place or another. Thus, people become tensed constantly. SLR also threatens the embankments. The risk increases during springtides in monsoon season when rivers are filled to the brim. Local people informed that in the last ten years hundreds of acres of land went under water of the Kobadak River in Gazipara and Gabbunia villages in Koyra. The Upazila Fisheries Officer at Koyra commented, "SLR is visible in Koyra (i.e. people's perception is that water level in the rivers is increasing gradually over time). People are worried about river erosion. The Union Council chairmen and members are always in tension – when the bad news of riverbank erosion comes. In tension, they cannot sleep well at night during the new moon and the full moon."

Erosions damage or wash away dikes of shrimp farms (or, entire farms), which causes shrimps to escape from ponds causing heavy financial losses to the farmers. We found, a number of shrimp farmers were forced to leave their occupation since they lost their farms because of riverbank erosions. Also, when the embankments are breached or washed away, water contamination happens with the intrusion of wastage into in the unaffected shrimp *ghers*. Similarly, predator species enter the ponds and cause losses to the shrimp production, something that we alluded to earlier.

5. Resilience to climate change

5.1. Adaptation to primary impacts on farming

The shrimp farming communities in south-western regions of Bangladesh apply specific strategies to tackle immediate effects on shrimps and *ghers*. At the shrimp fry collection level, climate disturbances directly affect the availability of shrimp PL in the rivers of the Sundarbans. The PL catchers cannot set their nets properly in strong currents and when water height increases. This affects their total amount of catch. On the other hand, though shrimp fry becomes plentiful for about 5–6 days during cyclones and storm surges, the fry catchers cannot operate in the stormy days. If they are on the PL catching trip in a jungle, they cannot come back to their homes in their villages on time. Consequently, they face food and drinking water shortages. Moreover, the annual peak period of *bagda* fry collection is the months of April–June which is also a peak time for cyclones hitting the coastal regions of Bangladesh. Thus, fry collectors become accustomed (or, resilient) to this problem and as adaptive strategy, they move out from the big rivers where they catch fry, and take refuge in canals in jungles during cyclones.

As discussed earlier, one of the reasons behind the death of shrimps in hot summer months is the shallowness of shrimp farms. *Bagda* farms are rectangular enclosures of varying sizes built in small depressions. The earthen walls, raised at each side to make the enclosures, are merely one meter high (Kais, 2017). The water depth in these farms becomes too low, thus making water temperature too hot during summer months. Although the optimum level of water depth in *gher* for *bagda* is 1.5 m (Roy et al., 2011), water depth in most of the *ghers* turns to be as low as 0.75 m. As a result, shrimps die frequently because of heat stress. As a preventive measure, some farmers now increase the depth of their farms by making trenches in the *gher* so that shrimps can take shelter there to avert heat stress during hot days. Also, since shrimps may die because of O_2 shortage in *gher* water as a result of increased shrimp density within a lower amount of water, some farmers now keep the stocking density of shrimp at moderate level. This is an adaptive measure to the climatic perturbations in the shrimp economy. During storm surge, floods, and excessively heavy rainfall, dykes of *ghers* submerge and shrimps escape. The farmers address this problem by investing in farm infrastructure. A section of the farmers have already increased the height of the *gher* dykes to avert escaping of shrimps. As a protective measure, a few farmers also put net around their *ghers* to prevent shrimp escape.

Transformation of previously large farms into small ones as an adaptive measure helps the farmers in managing their farms easily as well as reducing the risk of greater loss. If death outbreak in shrimp occurs in one *gher*, the farmer, to minimize the loss, can quickly take protective means for other farms through, for example, quickly harvesting shrimp from them. In order to make the PL hatched in high salinity[12] hatcheries in south-eastern Cox's Bazar adapting to a lower salinity farm area in the south-western Khulna region, a number of *nauplii* centres [nurseries] have developed in the region. These nurseries bring shrimp seed at *nauplii* stage and grow them in controlled tanks, exchanging water regularly and making the PL adjusted with *gher* water, for few days before the PL are sold to the farmers, who then culture them in grow-out ponds (*ghers*). All these measure, however, incur additional costs borne by the farmers.

5.2. Resilience at household level

If a shrimp farm suffers due to disasters or virus, the farmer incurs loss and consequently his household has to bear the brunt. Even if a small-scale shrimp farmer loses his entire production once in a year, he may recover the loss within the season. Generally, as found in our ethnography, a farmer experiences production failure once in a season. More than one production failures in a year leave severe household level impacts, depending on the farmer's economic status. Household of any small-scale shrimp farmer can be severely affected if there is a sudden large-scale calamity like cyclones and storm surges. In addition to shrimp farmers, households of shrimp fry collectors and other local-level stakeholders are also affected directly or indirectly, in varying degrees, because of weather shocks and climatic changes. When affected by income loss from shrimp due to weather shocks or climate change hazards, households in shrimp communities tend to rely on multiple coping mechanisms and resilience schemes. We have discerned at least three broad coping strategies in responding to cyclone hazards: consumption smoothing, income smoothing, and reducing investments in human capital (see also, Nguyen and Wodon, 2015; Ahmed, 2013).

As part of *consumption smoothing*, when confronted with a negative income shock such as production failure in shrimp due to weather and environmental hazards, households accumulate reserves in good times, which they can use in crisis periods. This is the most common consumption smoothing strategy in the study areas. The affected households spend their savings in bad times. The farmers who make profit earlier can spend from their savings during disasters. Since they apprehend disasters, they tend to make savings to use during calamities. If a shrimp-farming household makes profit by the end of a given culture season, it saves it for using in the next season. Although this is understandably the most common household response to production loss due to climate change, in reality, the aquaculture community cannot make significant amount of profit from shrimp every year. Moreover, households that are forced to spend their own savings every year to face crises become trapped in a vicious cycle in which they cannot have upward economic mobility in the society.

The households who do not have enough savings to meet the loss and restart shrimp stocking in *ghers*, generally borrow money from neighbors, friends or relatives. If this does not work, the farmers take loans from local moneylenders, NGOs and banks. Some distressed

[12] Ideal level of water salinity in bagda hatchery is 29–34 ppt (FAO, 2007).

households also sell poultry, reserved food grains, livestock or other minor assets. To recuperate greater loss, the households also sell or pawn other valuable assets such as land and jewelry as a further consumption smoothing strategy. The lower middle class families, including shrimp fry collectors, generally adopt this option as a means to cope with the adverse situation. But selling productive assets like land may have long-term negative effects on the households' income and overall livelihoods. Along with above mechanisms, afflicted households curtail family consumption expenses. This is very common practice during income shocks among fry collectors and small-scale farmers despite the fact that about half of the population in these areas are already below the poverty line, consuming only 2122 kcal/person/day or less (UN, 2010).

The second category of household responses entails *income smoothing* through diversifying a household's sources of income and making those sources less exposed to climate chaos (Wodon, 2015). Since paddy or other agricultural crops do not grow well in more than 1 million ha of land in the saline region (Roy, 2014; Islam, 2008a, 2008b, 2008c), and even the newly invented saline-tolerant rice varieties cannot endure the salinity level in water and soil in the areas (Roy, 2014), the aquaculture communities' most common income smoothing strategy is to diversify aquaculture practices. If *bagda* production drastically falls due to viral attack or other shocks, the farmers depend on other aquatic species that survive despite the shocks. Some carp and other species of fish such as grass carps and mono-sex tilapia (which they call as *shada machh*, meaning "extra white fish") are cultured with *bagda*. In addition to cultured species, some other species (locally called as *bajey machh*, meaning by-products) including *tengra* and *fassey* enter into *ghers* when water is exchanged, especially in *shorboraho ghers* in Mongla area. Farmers get some earnings from these cultured and non-cultured fish species.

In the current salinity regime, there is a narrow scope for diversifying livelihoods beyond aquaculture. Some households sometimes attempt to cultivate *aman* rice in the lean season of shrimp, although the productivity is usually low due to water and soil salinity. Shrimp farmers are generally reluctant to cultivate rice in their lands, yet some of them cultivate this variety as an income smoothing technique. Some households tend to grow vegetables in highlands and courtyards for limited time with little success. Similarly, few households seek off-farm employment in the locality as a response to economic shock due to adverse climatic and environmental conditions including salinity ingress.

Due to seasonal or temporary displacement in the coastal Bangladesh, circular migration is a common phenomenon in the lower strata of society. Migration is a socially embedded process, which is generally perceived as an indicator of low adaptive capacity of individuals or communities to stressful changes in the environment (Adger, 1999; Brooks et al., 2005; Salik et al., 2015). However, considering the broader perspective of migration in the context of adverse impacts of climate change, instead of treating migration as a threat, it can be viewed as a form of coping strategy for the affected households (Barnett and Webber, 2009; Scheffran et al., 2012). As an income smoothing strategy and as a soft adaptation measure of temporary livelihood diversification in the lean period or after a shock, some farmers search employment outside the locality as day labors or agricultural laborers. These temporary migrants generally go to nearby agricultural (rice cultivating) areas such as Jessore, Mollahat, Gopalgonj or to towns such as Dhaka or Khulna. Another coping option for the affected households is to migrate out permanently. Households migrate from the area in extreme adverse conditions. After *Aila*, for example, as many as 40,000 people migrated from Koyra upazila alone (UN, 2010). Similarly, Nguyen and Wodon (2015) found that 10% of households migrated from the Sundarbans permanently, and 16% sent a household member away for work.

People living in coastal ecosystems have just three options for adaptive response to climate shocks and variability: protection, accommodation, and retreat (Klein et al., 2001; Sterr, 2008; Tol et al., 2008; Saroar and Routray, 2013). Though 'protection' through construction and maintenance of large-scale coastal infrastructure may be effective in addressing the climate change threats, by and large, it is beyond the capacity of private or community interventions at local levels (Saroar and Routray, 2013; World Bank, 2000). Similarly, 'retreat' through emigration from the whole area (at least 25 million people would need to evacuate from the exposed coastal areas in Bangladesh) are neither within the reach of nor feasible for the local communities. Thus, the coastal shrimp farmers in Bangladesh have the only option to accommodate by reducing sensitivity and enhancing own adaptive capacity in order to offset negative impacts of climate change on the shrimp sector. Through effective resilience efforts at local and community levels, Bangladesh can minimize the loss from the brunt of global climate change.

6. Conclusion

Vulnerability to extreme weather events and gradual climate changes and the ability of households and communities to be resilient to such conditions have become a major concern in the current development discourse. This study provides new insights into, albeit preliminary, the extent to which aquaculture communities in Bangladesh – located at the bottom of the local supply chain – are affected by and resilient to climate shocks and changes. Being at the receiving end of global climatic disasters, aquaculture sector in Bangladesh is prone to various shocks and cataclysms generated by, for example, cyclone and storm surges, increase in atmospheric and water temperature, draught, heavy rainfall, intrusion of salinity, sea level rise, and erosions of riverbanks.

Devising adaptive measures in responding to the disasters induced by climate change seems to be the only option. As the study shows, shrimp farming communities' adaptation and resilience efforts are interlinked with various coping mechanisms in the coastal areas, such as the generation of alternative livelihood opportunities, community awareness, construction of coastal embankments and cyclone shelters, mixed culture of prawn-shrimp to address salinity intrusion, building higher dikes around aquaculture farms to deal with floods, and development of water irrigation facilities. However, if a shrimp farm is affected by weather shock or environmental and climate change, the responsibility of adaptation and recovery rests almost solely on the *gher* owner or cultivating farmer in charge. Households in shrimp communities rely on multiple coping mechanisms and resilience schemes such as consumption smoothing, income smoothing, and migration.

Overall, the capacity of shrimp farming communities in the lower end of the commodity chain, farmers and fry catchers in particular, is in general low. Most small *bagda* farming households in Bangladesh, as described in our analysis, do not seem to be resilient in any meaningful sense. As the paper shows quite clearly, they are highly vulnerable to a variety of shocks, and in many cases they appear to be barely getting by, with many of the coping (adaptation) strategies deployed either only marginally effective, or seeming to facilitate only the eking out of a minimum level of reproduction, sometimes culminating in them exiting farming entirely.

Shrimp farming is the main source of livelihoods for people living in the coastal region. The technical measures taken at the farm level are the outcome-oriented resilience to climate change since they can be viewed as spontaneous responses. The income-smoothing and consumption-smoothing strategies, on the other hand, act as process-oriented mechanisms that enhance the farmers' resilience to climate anomalies. These strategies apparently seem to be the signs of the farmers' vulnerability; however, if we look deeper into the issues we find that the strategies act as their adaptive capacity as well, which enable them to survive and sustain in a harsh environment at least to some extent.

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